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APPLICATION OF COOLANT-CHIP-EJECTOR DRILLING

by

RAYMOND A. KIRSCHBAUM

OCTOBER 1977

ENGINEERING DIRECTORATE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A program was conducted to evaluate the Sandvik coolant-chip-ejector drilling system for manufacturing purposes at Rock Island Arsenal. The Sandvik "Ejector Drill", which has an insert-type head with unique cutting geometries, produces small chips which are swept back through a center tube of its annular tool shank by the coolant. A series of tests were performed on two materials, namely, AISI 4140, a low-alloy steel, and CG 27, an iron base superalloy. The two materials presented considerably different machining characteristics, thereby providing a			

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20. ABSTRACT (cont)

basis to determine the usefulness of the Sandvik drilling system.

Drilling of deep holes at speeds comparable to those of gun drills and feeds comparable to those of twist drills was possible with accuracies and surface finishes equivalent to those obtainable by reaming. Surface hardening of the work material was lower than that caused by gun drilling and bore reaming, especially when drilling the CG 27 alloy. Consequently, multistep operations of machining, straightening and stress relieving were eliminated in many instances. Machining rates up to ten times faster than twist drilling and up to twenty times faster than gun drilling were realized.

The new drilling system was adaptable to existing in-house boring equipment and substantial cost savings have been realized, especially in the machining of Howitzer recoil mechanism components. Recommendations are made to expand the use of the Sandvik tool to include boring and trepanning. (Kirschbaum, R.)

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FOREWORD

The work was authorized as part of the Manufacturing Methods and Technology Program of the U.S. Army Materiel Development and Readiness Command and was administered by the U.S. Army Industrial Base Engineering Activity.

Production test work, data collection, and time and cost analyses were conducted by John T. Coleman, a former employee of the Arsenal Operations Directorate, Rock Island Arsenal. Mr. Coleman's work also involved the redesign and relocation of the drill guide bushing from which the successful drilling of the CG 27 alloy resulted.

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INTRODUCTION

A study was made to evaluate the Sandvik coolant-chip-ejector drilling system and to determine its effectiveness and economy for use in manufacturing at Rock Island Arsenal. The intended goal was to improve upon the slow, costly and inaccurate methods of hole-making.

In the development of machining, improvements in drilling efficiencies have been less progressive than in turning efficiencies. Cutting tool materials such as carbides and ceramics could not be directly applied in drilling as in turning because of acute differences in their respective cutting mechanisms, e.g., the mechanical and thermal stresses to which a single-point turning tool is subjected are lower and more uniform than those stresses to which a drill is subjected. These differences in stresses are related to their geometric constructions and to their related cutting actions. The straight, side-cutting edge of a turning tool cuts a relatively uniform, curved, ribbonlike chip whose velocity is relatively uniform over the side-cutting and chip-breaker edges. However, a twist drill cuts a spiraled, tapered chip, formed over its width, at an increasing velocity from the dead-center dull point to the drill-lip corner. The dead-center, drill point is the axial center of the chisel edge at which the rotational cutting velocity is zero.

Presently, carbide and ceramic tool materials used for the turning of ferrous alloys cannot be used in twist drilling these alloys. This is attributable to the fact that neither of these hard, abrasive-resistant materials can withstand the high shock that occurs in the irregular low-velocity chip-formation at the chisel edge of a twist drill. The drilling of ferrous alloys with an ordinary carbide, twist drill will usually result in failure of the drill edges or in drill breakage. The turned chip usually breaks away from the cutting zone with predictable regularity; but the drill chip usually twists into the drill flutes before breaking in an irregular manner. Such drill chips contribute to uneven chip-formation at the lip-cutting edges. These edges constantly cause a change in actual cutting velocity due to the winding and unwinding of the springlike drill body. Consequently, twist drill materials preclude the use of carbides and ceramics since they are subjected to unusually high shock stresses. Ordinary drills are generally made of high-speed steel (HSS) and are limited to cutting speeds substantially lower than the speeds of carbide or ceramic turning tools. When twist drills are made of carbide, the performance of the tool is adversely affected.

The difference between the cutting rates of turning tools and conventional twist drills is shown in Table 1.

TABLE 1

CUTTING RATES OF TURNING TOOLS VS. TWIST DRILLS

<u>MACHINING OPERATION</u>	<u>TOOL MATERIAL</u>	<u>SPEED SFM</u>	<u>FEED IPR</u>	<u>TIME (MIN.) FOR 60-INCH WORKPIECE</u>
Turning				
	Carbide	275-350	.007-.015	9.1
	HSS	40-60	.007-.015	57.1
Drilling				
	HSS	35	.009	49.8
	Carbide	150	.001	104.7

The examples in Table 1 are obtained from the Machining Data and Engineering Guidelines (Revised); and are concerned with the machining of 4130, 4140, and 4150 steels (quenched and tempered to a hardness of 325 to 375 Brinell). Times were calculated from the mean values of recommended speeds and feeds for 1-inch diameter drills and for the turning of 2-inch diameter workpieces. Analysis of Table 1 shows that the tool traverse rates from the combined speeds and feeds of ordinary drills lag behind those of single-point turning tools. Generally, in the manufacturing of cylindrical workpieces, drilling may require 100 to 1700 percent more time than turning. It is therefore obvious that if the mechanism of chip formation in drilling operations could be changed to minimize stressing of drill edges, perhaps by changes in geometric design, then drilling efficiencies could be improved substantially.

Coolant-Chip-Ejector Drilling System

The coolant-chip-ejector drilling system tested and evaluated in this study was commercially developed by the Sandvik Steel Company. The system comprises a few, easily assembled components adaptable to heavy-duty lathes, drill presses, and boring mills having a large-volume, built-in or auxiliary, medium-pressure coolant supply. The drilling components for a rotating workpiece are shown in Figure 1.

The drilling components, heads, tubes, collets, etc., are presently available in thirteen standard size ranges from 0.787-0.858-in. dia. to 2.213-2.500-in. dia. When ordered, the heads are ground to the size required, and the insert chip-breaker grooves are placed and shaped for the work material specified, with recommended cutting speed and feed ranges. All drill

¹ "Machining Data and Engineering Guidelines (Revised)", Technical Report No. SWERR-TR-72-60, Research Directorate, GEN Thomas J. Rodman Laboratory, Rock Island Arsenal.

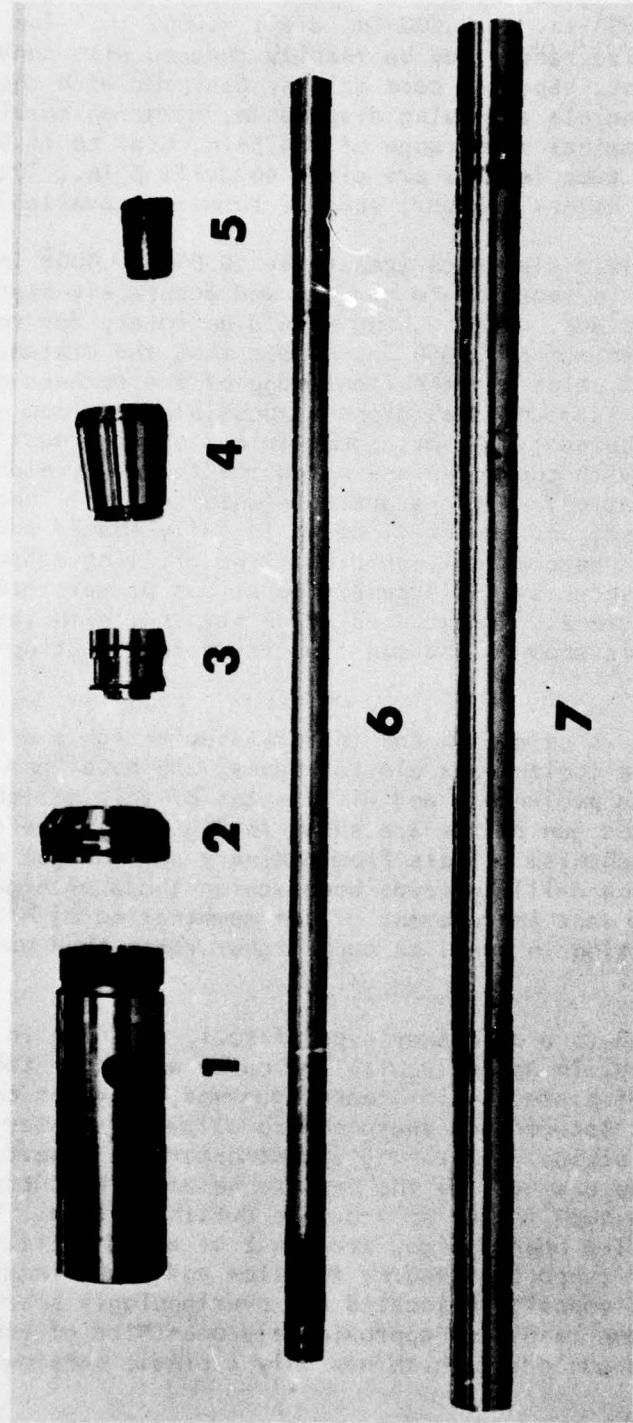


FIGURE 1.

Drilling Components.

1. Adaptor, 2. Nut, 3. Sealing Bushing (O-ring),
4. Collet, 5. Drill Head, 6. Inner Tube, 7. Outer Tube

diameters are ground with no positive tolerance and with negative tolerance as follows: 0.787-in. to 1.130-in. dia.: -.0005 in.; 1.130-in. to 1.185-in. dia.: -.0006 in.; and 1.850-in. to 2.500-in. dia.: -.0007 in. The drill diameters, within each size range, may be readily reduced with conventional carbide grinding equipment. Special core drills, designed with the same coolant-chip-ejector principle and using disposable, clamp-on carbide inserts, are available within a nominal size range of 0.875-in. dia. to 14.5-in. dia. Standard inner and outer tube lengths are sized to drill 5 in., 10., 19., or 36 in. deep, or through, holes. Longer, special tubes are available.

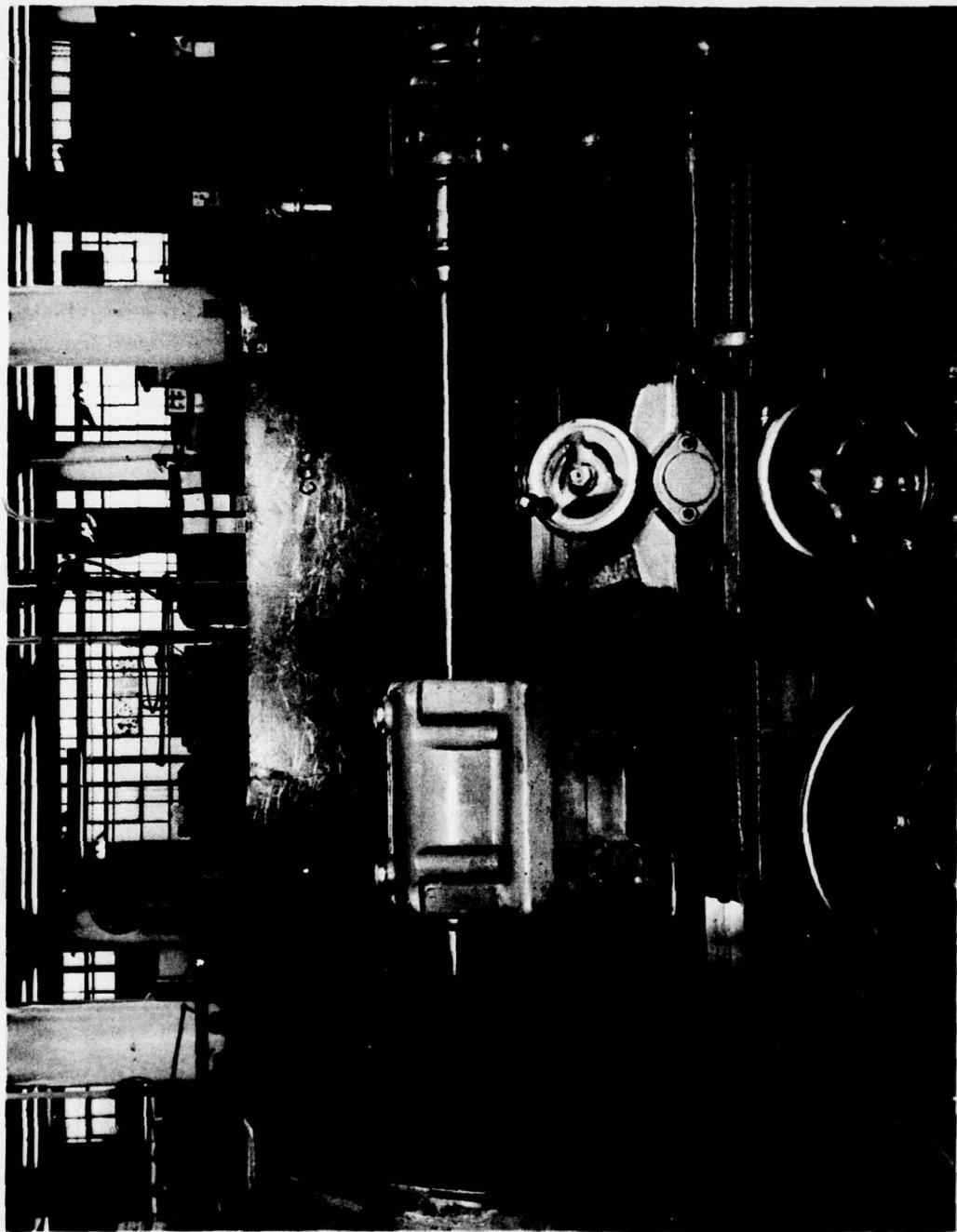
A guide bushing of close clearance (generally .0003 to .0008 in. over nominal drill diameters) is required to rigidly and accurately start the drill head into the workpiece. The bushing should be rotary for rotating drills and should be a minimum of 0.350 in. longer than the distance from the leading, drill insert point and the front edge of the screwed-on outer tube. The guide bushing is mounted as close as possible (maximum spacing of 0.040 in.) to the workpiece; however, some minimum spacing must be maintained to avoid contact with the workpiece which may thermally elongate during the drilling operation. After starting, (when the drill head has passed through the bushing, and the drill point is fully seated and cutting in a workpiece) the drill becomes self-guiding. The drilling assembly is shown in a boring lathe setup at the Arsenal Operations Directorate of the Rock Island Arsenal, Figure 2. The mounted guide bushing, with the drill head projected through, is shown withdrawn from its normal cutting position close to the workpiece.

This drilling system is unique in the interrelated design and function of the drill head and the coolant and ejector tubes, the outer and inner tubes, respectively. The evolution and differences of this design from ordinary twist, spade, and gun drills are shown in Figure 3. The coolant-chip-ejector drilling mechanism differs from ordinary carbide gun drills in performance by allowing drilling feeds approaching those of high-speed-steel twist drills. The vast improvement of the combination of high speeds and feeds allows penetration in steel at much higher rates than possible with conventional drills.

The drill head, which is a throwaway type of tool, is shown in Figure 4, and schematically cutting, in assembly with the outer and inner tubes, in Figure 5. It consists of brazed, chip-breaker grooved, tungsten carbide (of various grades) tips located and sharpened to allow off-center starting and overlapping cutting action. A brazed, tungsten-carbide insert, wear pad is located on the outside diameter of the head to balance the cutting forces and accurately align the tool in its self-guided cutting action. The difference of this drilling head design, from that of a gun drill, significantly affects axial and support pressure, friction and power requirements in drilling. The three, oppositely located and overlappingly spaced inserts produce narrower chips and result in approximately one-third of the tangential cutting forces of a gun drill which has only a single cutting edge.

FIGURE 2.

Drilling Assembly.



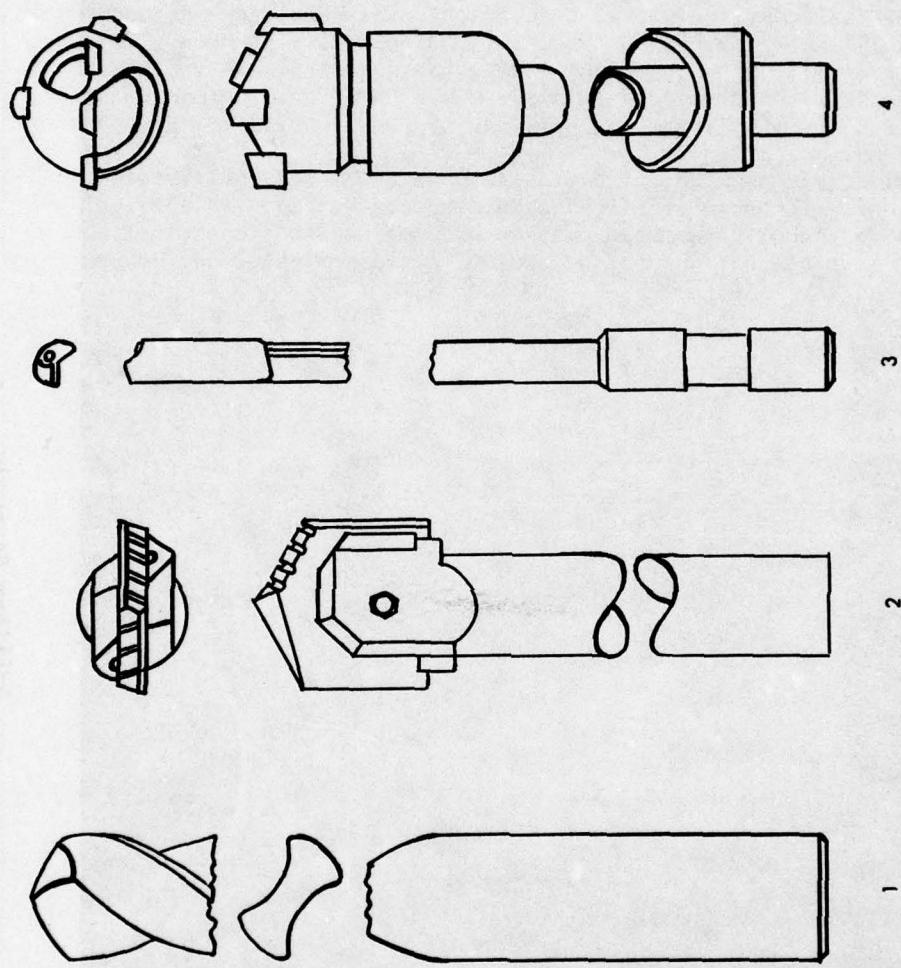


FIGURE 3.

Drill Design.

1. Twist Drill,
2. Spade Drill,
3. Gun Drill,
4. Coolant-Chip-Ejector Drill

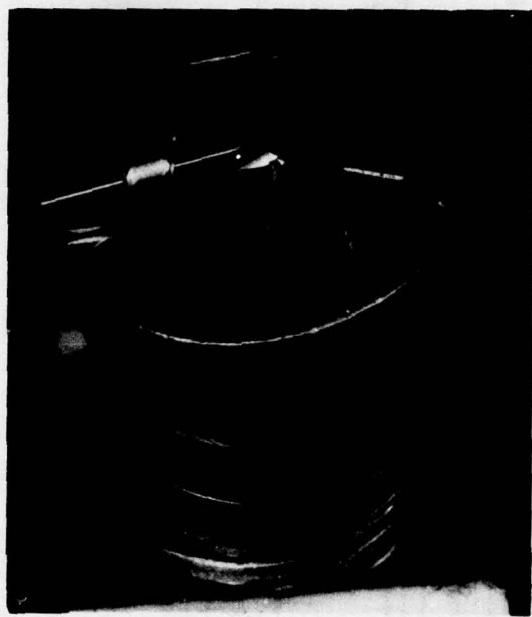


FIGURE 4

Coolant-Chip-Ejector Drill Head

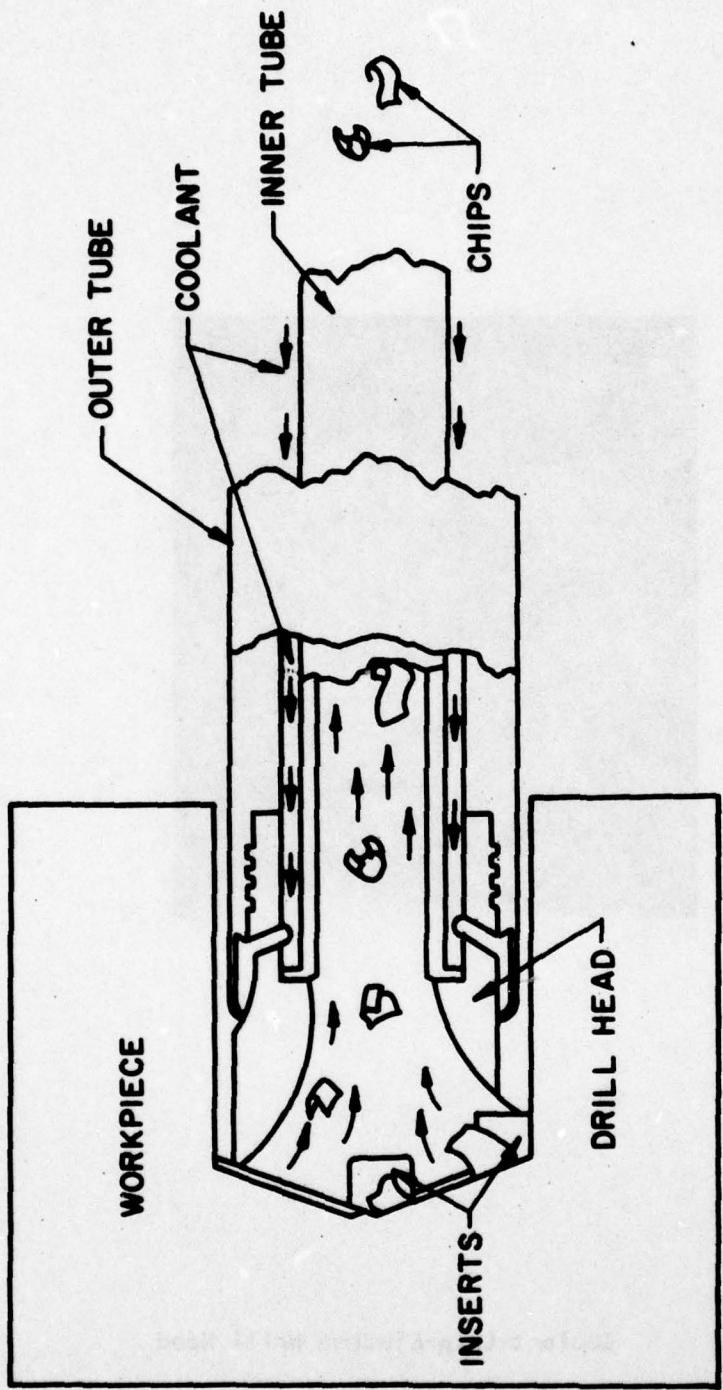


FIGURE 5.
Schematic of Drill Head and Tubes in Workpiece.

Consequently, a better workpiece surface finish, with a substantially reduced work-hardened zone, is produced while using the coolant-chip-ejector tool. Typical cutting forces for 2.500-in. dia. drilling of 220-240 BHN, 1045 steel at 310 SFM (500 RPM) and 6.3 IPM (.0126 IPR), are 318-lb. torque, and 3970-lb. thrust. Further details of cutting forces are given in Table 2.

In assembly, the buttress-threaded, drill-head shank is screwed into the front end of the outer tube through which the incoming coolant flows to the small outlet holes spaced peripherally at the forward end of the shank. The inner tube, through which the chips and used coolant are ejected, is seated on a chamfer, forward of the outlet holes, inside the drill head. The rear end of the inner tube is seated on a chamfer inside the coolant adapter, and has peripherally spaced venturi slots. These venturi slots bypass some incoming coolant from within the outer tube to provide a vacuum throughout the inner tube and drill head; the vacuum produces a suction effect for smooth, steady, coolant and chip ejection. Summarily, the coolant enters the outer tube through the adapter, establishes a rearward suction by partial flow through the inner tube venturi slots, and flows forward and out of the drill head shank outlet holes. It then passes over the drill body and point, in the spaces between the wear pad and cutting inserts and the workpiece, to the areas of the insert, cutting edges and the workpiece chips. The coolant then aids in chip-breaking and carries the cut chips through the two openings in the face of the drill point, back through the inner tube, and exits from the adapter into a reservoir for screening, filtering, cooling, and recycling. A coolant-chip deflector, attached to the rear of the adapter mount, and a chip-catcher screen are shown in an end view of the boring lathe setup in Figure 6.

Although the 0.787-in. dia. size requires only approximately 5HP in drilling normalized steel (at 0.004-0.007 inch-per-minute feed and 900-1200 RPM), this minimum size is presently dictated by chip-flow control. However, at the 2.500-in. dia. size, where 30HP is required to drill normalized steel (at 0.007-0.013 inch-per-minute feed and 350-500 RPM), available horsepower may often be a limiting factor. Similarly, while a coolant flow of only 16 gpm at 210 psi is required for the 0.787-in. dia. drilling, 42 gpm at 140 psi is required for the 2.500-in. dia. and, although these pressures are substantially lower than those required for gun-drilling, the volume is higher and requires higher capacity pumping, filtering, and cooling for large size drills. In general, a cutting fluid velocity of approximately 1.64 feet-per-second is required for horizontal drilling, and a velocity of 2.625 feet-per-second is required for vertical, downward, drilling.

TEST RESULTS AND DISCUSSION

The advantages of general, carbide coolant-chip-ejector drilling for gun drilling were reported by the British Trepanning and the American

TABLE 2

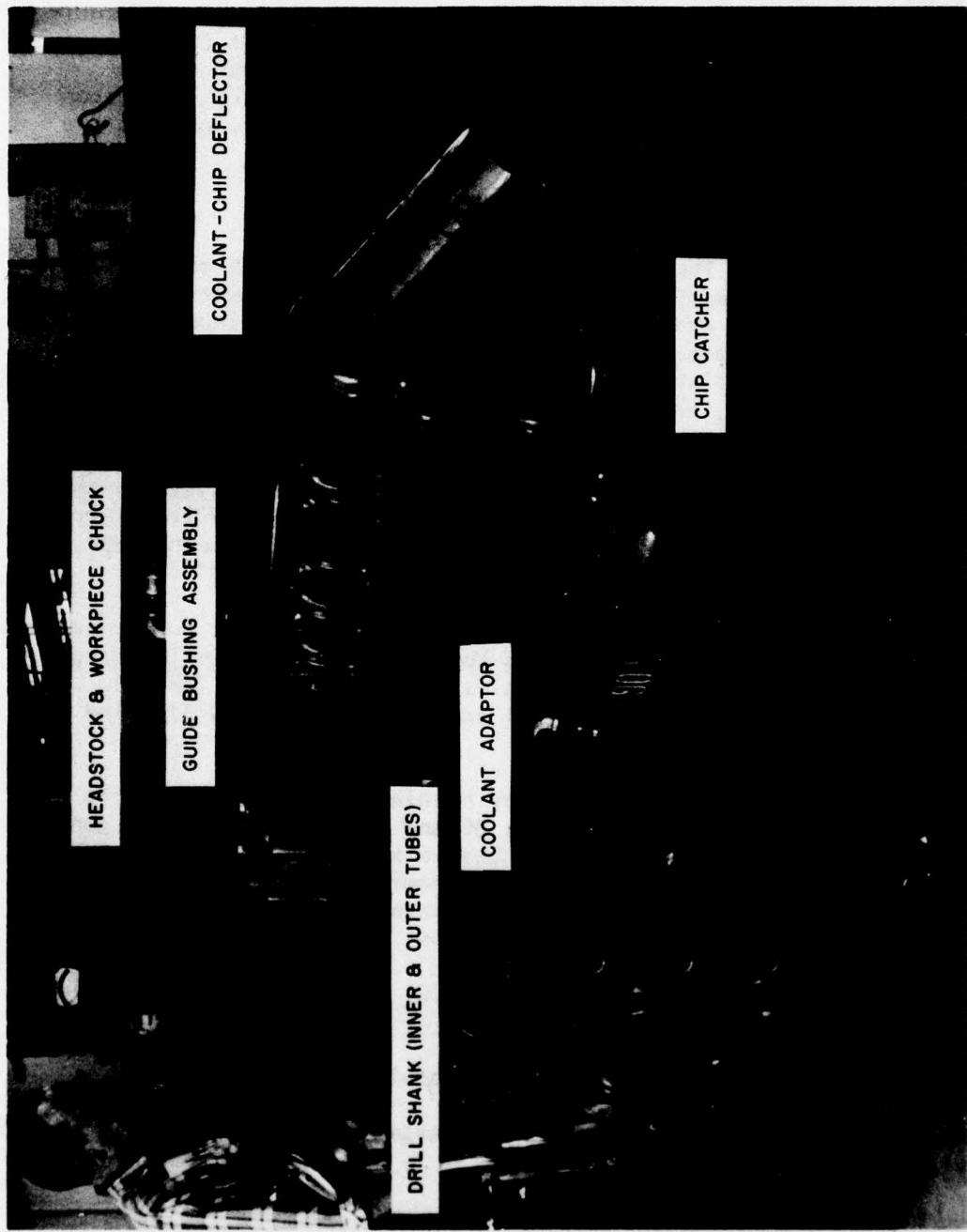
COOLANT-CHIP-EJECTOR DRILLING FORCES*

(Work Material: SAE 1045 steel, normalized, 220-240 BHN)

<u>Drill Diameter</u>	<u>Speed</u>		<u>Feed</u>		<u>Torque</u>	<u>Thrust</u>	<u>Net Power</u>
<u>(In.)</u>	<u>RPM</u>	<u>SFM</u>	<u>IPR</u>	<u>IPM</u>	<u>(Ft/Lb)</u>	<u>(Lbs)</u>	<u>(HP)</u>
1-3/4	500	230	.0066	3.3	87.0	2200	6.4
	500	230	.0105	5.1	125.0	2650	9.3
	625	285	.0088	5.5	108.0	2300	10.0
	625	285	.0120	7.5	141.0	2750	12.7
1-7/8	500	245	.0072	3.6	101.0	2200	7.5
	500	245	.0099	5.0	144.0	2640	9.9
	625	310	.0088	5.5	123.0	2280	11.3
	625	310	.0120	7.5	153.0	2750	14.2
2-1/8	400	225	.0083	3.3	159.0	2640	9.2
	400	225	.0110	4.4	195.0	3120	11.5
	400	225	.0126	5.0	232.0	3520	13.4
	500	280	.0083	4.2	152.0	2550	11.2
	500	280	.0110	5.5	195.0	3000	14.3
	500	280	.0126	6.3	217.0	3400	15.9
2-13/32	400	250	.0083	3.3	231.0	3050	13.4
	400	250	.0110	4.4	297.0	3790	16.2
	500	310	.0083	4.2	235.0	3000	17.2
	500	310	.0110	5.5	282.0	3610	20.7
	500	310	.0126	6.3	318.0	3970	23.4
29/32	990	235	.0055	5.45	7.2	835	1.1
	990	235	.0077	7.6	21.7	1750	3.2
	1570	335	.0066	10.4	18.2	975	4.2
	1570	335	.0088	13.8	21.7	1230	5.0

* Furnished by Mr. Ralph St. Clair, Clairco Tool Co. (Sandvik Distributor, Davenport, Iowa)

FIGURE 6. End View of Boring Lathe Setup with Coolant-Chip Deflector and Chip Collector



Society of Tool and Manufacturing Engineers.² However, the improved Sandvik drill head design was first noted, in this Laboratory, in an abstract of US Patent No. 3,274,863.³ Drilling system operation and costs from "Sandvik Coromant Ejector Drill" (CT-8-B, Sandvik Steel, Inc., 1966) were reviewed with manufacturing personnel of Rock Island Arsenal. A drill testing program was then planned and accomplished through the co-ordinated efforts of manufacturing and laboratory personnel of the Arsenal and the local Sandvik tool distributor. The program was designed to initially evaluate the coolant-chip-ejector drilling of candidate weapon systems materials and, if proven desirable, to extend the concept to the drilling of actual weapon components.

A. Material Tests

1. 4140 Steel. The first tests were conducted with the services of the Mississippi Engineering Company, Grand Mound, Iowa, where a new Stanley Drilling machine was located. This was necessary since machines of sufficient capacity and adequate design were not readily available at Rock Island Arsenal. The English-built Stanley machine was specifically designed with the rigidity, power, variable speed and feed ranges, and high-volume coolant required to gain maximum advantage of the coolant-chip-ejector drill in high-production drilling. The machine was equipped with eight spindle speeds, a 35HP drive motor, a 180 gal. cutting-fluid supply system with 10HP pump motor, and a dual rate, infinitely variable feed ranging from 1 to 8-1/2 IPM or 1 to 17 IPM. The speed intervals of this machine are 400, 476, 590, 727, 877, 1048, 1298, and 1600 RPM.

The workpieces and drill heads, ranging from the smallest to the largest standard available sizes, were submitted to the Mississippi Engineering Co. for the first test drilling and the details are presented in Table 3. The compositions of the low alloy 4140 steel and the iron base CG 27 alloy are shown in Table 4.

The cutting fluid used in the Stanley machine was a mixture of the Anderson Oil and Chemical Company Viscool No. 36 and Shamrock DX special gun drilling and trepanning soluble oils. The base mixture was 10 parts water to 1 part Viscool No. 36. Ten gallons of the Shamrock DX were added to the 180 gallon cutting fluid supply system to compensate for hardness of the local water. A pump supply pressure of 190 psi was used throughout these tests.

² Gun Drilling, Trepanning and Deep Hole Machining, ASTME, 1967

³ "U.S. Official Patent Gazette," U.S. Department of Commerce, 27 Sep 1966, Sandvik Steel, Inc.

TABLE 3

TEST WORKPIECES AND DRILL HEADS

<u>Material</u>	<u>Diameter (Inches)</u>	<u>Length (Inches)</u>	<u>Hardness</u>	<u>No. of Pieces</u>	<u>Drill Head (In. Dia.)</u>
CG 27*	2.75	5.5	93 RB	2	2.408
4140**	2.75	26	39 Rc	2	2.408
4140	1.125	28	35 Rc	3	0.787
4140	2	15	36.8 Rc	2	1.180
4140	2	15	217 BHN	2	1.180

* Crucible Steel Company Designation

** Federal Standard No. 66b

TABLE 4

COMPOSITION (WEIGHT PERCENT) OF ALLOYS 4140 AND CG 27

<u>Element</u>	<u>4140</u>	<u>CG 27</u>
Carbon	0.38-0.43	.02-.08
Manganese	0.75-1.00	---
Phosphorous	.04	---
Sulfur	.04	---
Silicon	0.20-0.35	---
Chromium	0.8 -1.10	12.50-14.00
Molybdenum	0.15-0.25	---
Aluminum	---	1.45- 1.75
Columbium	---	.003-0.015
Titanium	---	2.30-2.70
Nickel	---	~39
Iron	Remainder	Remainder

The first drilling test cuts were made with the intermediate size, 1.180-in. dia. drill head, at 181 SFM (590 RPM) and 5 IPM (.0085 IPR) in annealed 4140 steel bar stock (217 BHN). Initial trials were not successful since discontinuous feeding of the drill was experienced. An action, such as this, could cause work hardening of the workpiece and damage to the machine. Consequently, until more familiarity with the drill system could be acquired, the setup was changed for 0.787-in. dia. drilling. A new workpiece of the same material was chucked, the new guide bushing was aligned and the feed mechanism was fully engaged. Drilling of a 15 in. through hole at 212 SFM (1048 RPM) and 5 IPM (.0048 IPR) was then accomplished. Drilling tests, using a new 0.787-in. dia. drill, were extended to include the same material heat treated to 36.8 Rc. Successful drilling of the workpiece was accomplished at the same speed and feed. The drilled hole surface finishes were 50-60 RMS for the annealed steel and 15-20 RMS for the heat treated steel.

Since some experience of the Sandvik drilling system was acquired, testing of the original 1.180-in. dia. drill and workpiece was attempted again. The feed was raised to 6 IPM (.0102 IPR at 590 RPM) to clear the built-up edge on the tool inserts and to cut through the work-hardened area caused by the feed stoppage in the first test. However, poor cutting was evidenced by poor curl, breaking, and surface finish of the chips. In the next test, with the speed increased to 727 RPM (142 SFM) and the feed at 6 IPM (.0083 IPR), the drill head inserts were broken. Then, in a return to the speed originally tried, 590 RPM (181 SFM), and the 6 IPM (.0102 IPR) feed, the chips clogged the ejector tube. Finally, after clearing the ejector tube, the 1.180-in. dia. head worked successfully at the combination of 181 SFM and .0085 IPR. Causes for the initial failures with the 1.180-in. dia. drill are not known. The discontinuous feeding of the drill could be attributable to improper locking of the feed mechanism or some variance in hydraulic pressure. However, it was apparent that the recommended speeds and feeds were accurate. All of the holes drilled were inspected with micrometers and bore gauges, and all were found to be within 0.001 in. of the drill diameters.

2. CG 27 Alloy. initial coolant-chip-ejector drilling of the CG 27 alloy proved to be very difficult, and was first judged by the Sandvik engineers to be unworkable or, at least, impractical. Prior experience in the turning of CG 27 alloy had shown the material to be tough and gummy, resulting in poor chip-breaking and poor surface finishes. Consequently, it was decided to use the large drill (2.409-in. dia) to augment tool rigidity, chip breaking and chip ejection while test drilling the CG 27 alloy. The lowest speed available on the Stanley machine, 400 RPM (245 SFM) was selected with feeds of 3 IPM (.0075 IPR) and 4 IPM (.010 IPR). However, cutting action was poor at both combinations of these parameters. Severe built-up edge of the tool and poor chip-breaking caused chip clogging in the ejector tube and resulted in unacceptable workpiece surface finishes and consequent chip-to-insert welding and insert breakage. The same results were experienced when a 1.180-in. dia. drill was tried at 400 RPM (121 SFM) and 5 IPM (.0125 IPR). At 476 RPM (144 SFM) and 6 IPM (.0126 IPR), the drill failed catastrophically with evident thermal damage on the outer inserts and mechanical seizing on all inserts.

It was decided that additional experimentation would be conducted by the Rock Island Arsenal and by the drill manufacturer at their plant in New Jersey. The approach was designed to make use of the empirical knowledge of personnel at both installations. The parameters varied were speed, feed, cutting fluid, fluid pressure and drill sizes. The CG 27 workpieces were successfully drilled using the data presented in Table 5.

Analysis of the data presented in Table 5 showed that slower speeds, and the use of sulfurized-chlorinated rather than water soluble cutting fluids yielded substantial advantages while drilling CG 27 in the age-hardened condition. It also proved advantageous to use a .0001 to .0002-in. guide bushing clearance rather than the recommended .0004 to .0010 in. clearance. Although tool wear was more severe than in drilling 4140 steel, there was no chip welding or damage to the cutting edge of the tool. Additional testing was performed on the CG 27 alloy in the annealed condition. There were no significant differences in drilling characteristics although the material was drilled somewhat more easily than when in the age-hardened condition. Speeds and feeds were somewhat higher than those used for the age-hardened material.

Test and evaluation of the coolant-chip-ejector drilling system included identification and establishment of the workable machining parameters, the necessary chip formation and size for proper chip flow through the drill head and inner tube. The respective sizes and shapes of desirable chip formation for the various inserts were determined and are shown in Figure 7. The process was demonstrated to all Arsenal supervisors responsible for major drilling operations; and the required control of chip formation and size was demonstrated in repetitive drilling of the 4140 steel test work-pieces.

B. Process Demonstration

This phase of the program was concerned with the test drilling of weapon components to provide the transition required from the simple hole drilling of bar stock to actual production workpieces. The weapon components, Figure 8, and the development of drilling operations are described in the following sections.

1. Howitzer 127 Gun Mount, Tube Piston, RIA Part No. 10895621. The piston, also called the "Potato Masher," is made from a 4140 steel forging and is heat treated to a hardness of Rc28-32. The method of fabrication, using conventional tools, was to gun drill to 1/2-in. dia, and then to "hog-nose" through-drill the 2-7/8-in. dia. by 44-1/4 in. long workpiece in 2 steps with stress-relieving and straightening of workpieces between each step. Initially, the blank is through-drilled to a 1.763-in. dia. (371 RPM, 161 SFM and .007 IPR/2.597 IPM). This is followed by boring to a 1.970-.013-in. dia. (371 RPM, 180 SFM and .007 IPR/2.597 IPM) before honing to a 2.000-in. dia. finish. The boring tool life, using this procedure, was low, usually less than 1 workpiece, and the insert failure was often catastrophic. Various examples of boring bit failures are shown in Figures 9 and 10.

TABLE 5

TEST DRILLING OF CG 27 ALLOY

	<u>New Jersey Test*</u>	<u>Rock Island Arsenal Test**</u>
Work Material		
Condition	Aged (35 Rc)	Aged (35 Rc)
Diameter	2-3/16 in.	2-3/16 in.
Length	5-5/16	36 in.
No. of Pieces	2	1
Speed		
Surface Feet Per Minute	70	59
Revolutions per Minute Feed	217	198
Feed		
Inch per Revolution	.0046	.007
Inches per Minute	1	1.4
Cutting Fluid		
Make	Stuart's Dascoline 88	American Anocut 209 BCS
Type	Water Soluble Oil	Sulfurized-Chlorinated Oil
Mixture	Straight	Straight
Pressure	180 psi	175
Drill Diameter	1.25 in.	1.180 in.

* 35 HP American lathe with 135 gallon coolant tank capacity.

** Speed and feed intervals available on the Rock Island Arsenal Axelson lathe used in testing are given in Table 6.

TABLE 6

SPEEDS AND FEEDS AVAILABLE ON AXELSON LATHE (30HP)

Speeds (RPM)

<u>Low</u>	<u>High</u>
218	750
170	584
108	371
84	287
56	198
45	154
30	101
23	80
14	50
11	38
8	27
6	22

Feeds (IPR)

"AC"	.0021	.0022	.0024	.0026	.0027	.0028	.0031	.0035	.0040
"AD"	.0042	.0045	.0048	.0052	.0055	.0058	.0062	.0070	.0080
"AE"	.0085	.0090	.0098	.0105	.0110	.0115	.0126	.0140	.0160
"AF"	.0170	.0180	.0195	.0210	.0220	.0230	.0250	.0280	.0320
"BF"	.0340	.0360	.0390	.0420	.0440	.0460	.0510	.0560	.0640

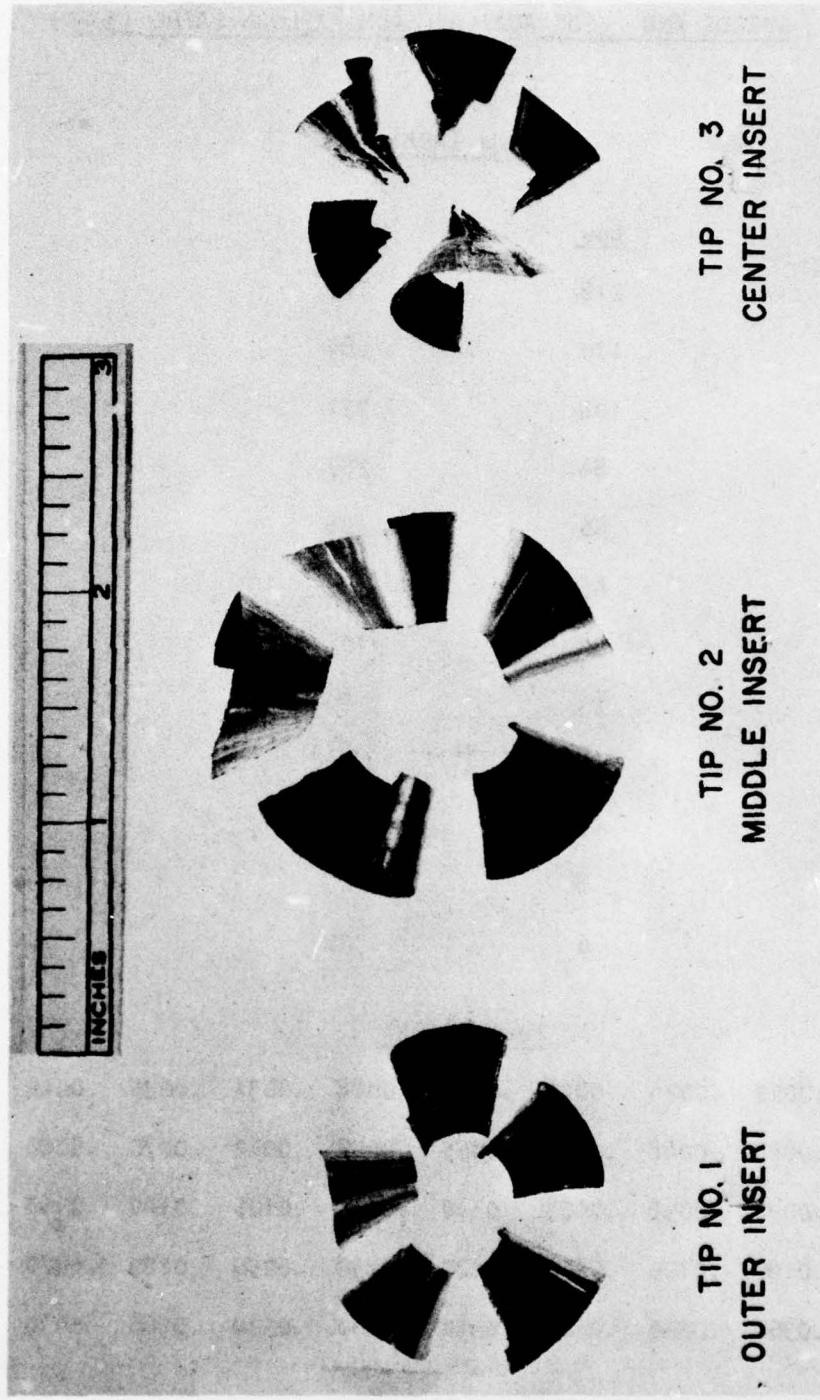


FIGURE 7.

Relative Chip Sizes and Shapes.

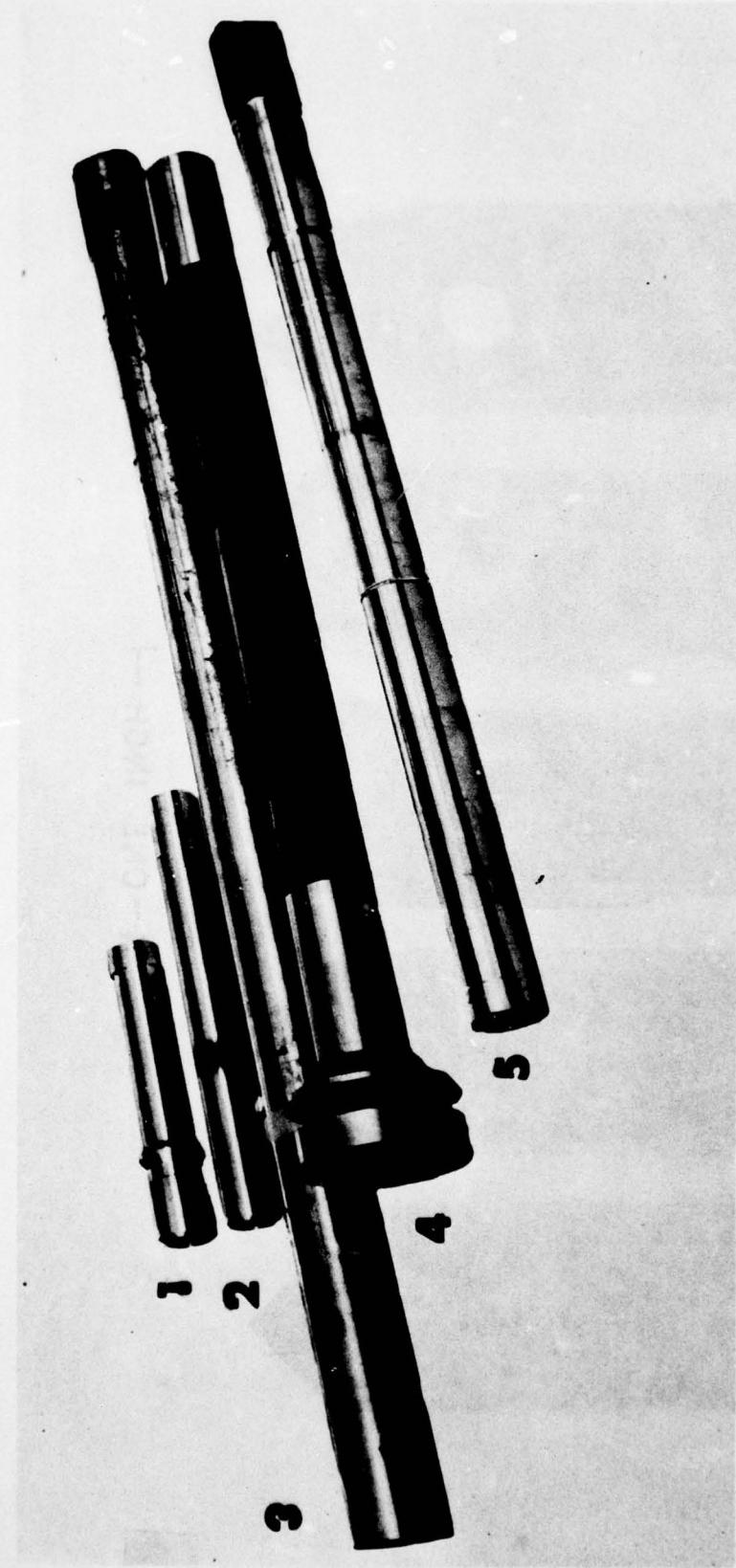


FIGURE 8.

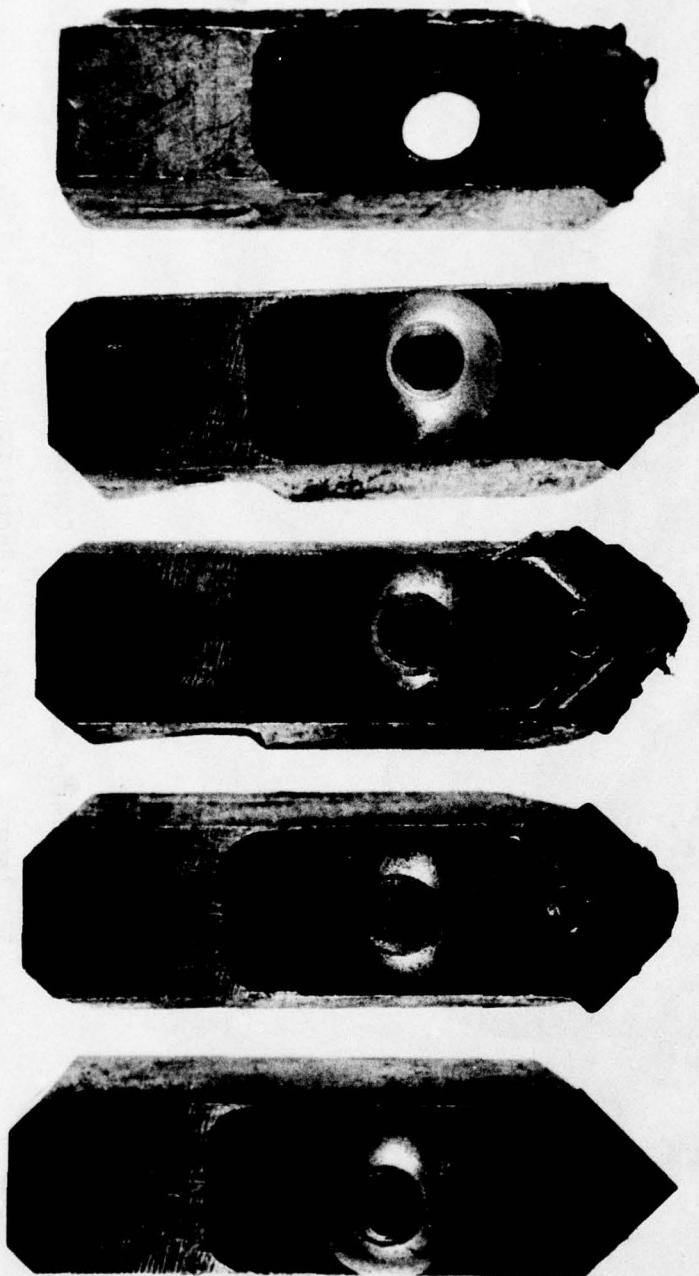
Test Workpieces of Weapons Components.

1. Regulator, 2. Cam, 3. Recoil Cylinder,
4. Tube ('Potato Masher'), 5. Gun Barrel

Top View of "Hognose" Boring Bit.

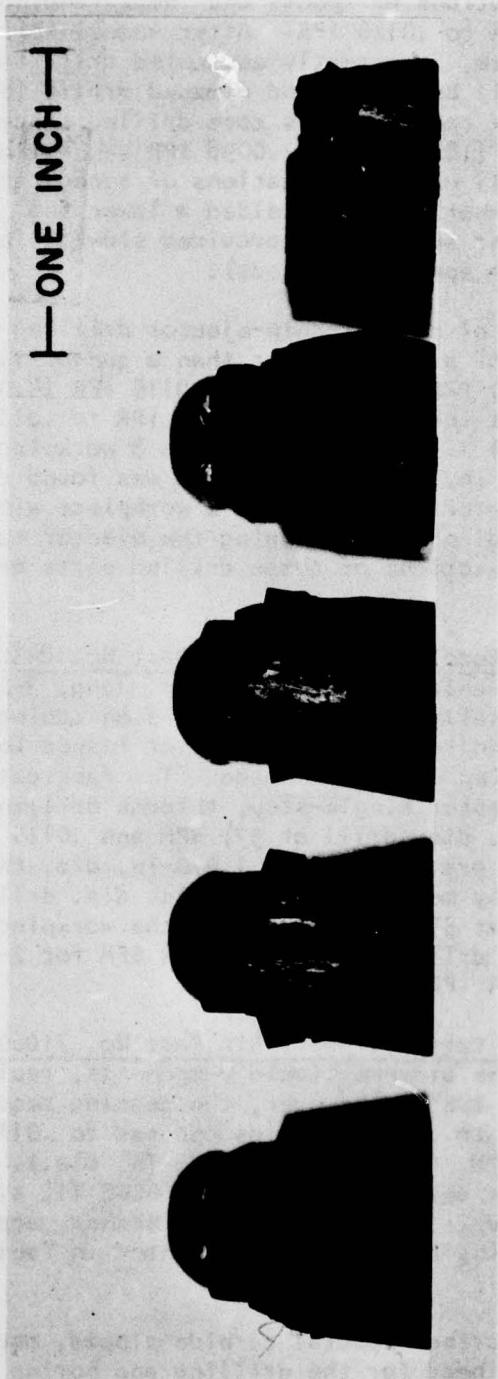
FIGURE 9.

— ONE INCH —



End View of "Hognose" Boring Bit.

FIGURE 10.



The coolant-chip-ejector drill was first tested in the gun-drilled forging at various combinations of speeds and feeds ranging from 287 to 584 RPM and from .0062 IPR to .0126 IPR. After some initial malfunctions of the lathe coolant system, incorrectly-assembled drill tubes, incorrectly-sized and located drill bushings, and damaged drills (by loose heads, tubes, and workpiece), the component was core drilled successfully to the 1.970-in. dia. at 371 RPM (180 SFM) and .0098 IPR (3.64 IPM). Tool life was 2 to 3 workpieces. All other combinations of speeds and feeds either damaged the drills (at higher feeds), yielded a lower tool life, of 1 workpiece or less (at higher speeds), or provided slower, less efficient penetration (at both lower speeds and feeds).

Continued development of coolant-chip-ejector drilling of the piston resulted in the drilling of a solid rather than a gun-drilled forging to the 1.970-in. dia., at 371 RPM (180 SFM) and .0115 IPR (4.08 IPM). It is observed that the feed is increased from .0098 IPR to .0115 IPR when solid material is drilled. Tool life, again, was 2 to 3 workpieces (approximately 88-1/2 in.-132-3/4 in. drilled), and, it was found that a worn drill could be stopped and a new drill started in a workpiece without adversely work-hardening the material or chip-clogging the ejector tube. Eccentricity readings from inspections of these drilled parts are presented in Table 7.

2. Howitzer 102 Recoil Cylinder, RIA Part No. 8432834. Testing was conducted in drilling this 4130 steel, 60-in. long, 3-1/4-in. O.D., workpiece which was originally procured as precision tubing. Here again, the "hognose"^{*} drilling and related operations of inspection, stress-relieving, and straightening were eliminated. The fabrication from tubing was changed to the much faster single-step, through drilling from solid bar stock with a 1.970-in. dia. drill at 371 RPM and .0115 IPR. Further testing on this component proved that the 1.970-in. dia. through drilling could also be eliminated by modifying a 2.000-in. dia. drill to provide a 0.12-in. internal radius at 53.44-in. depth in the workpiece. Drilling speed for this 2-in. dia. drill was 371 RPM (194 SFM for 2-in. dia.), and the feed remained at .0114 IPR.

3. XM198 155 Howitzer Cylinder, RIA Part No. 71D608. Drilling of solid stock, similar to the aforementioned components, replaced the conventional use of aluminum tubing; however, the testing required an adjustment of the feed downward to .0062 IPR, (as opposed to .0115 for the 4130 and 4140 steels) at 371 RPM (231 SFM for 2.375-in. dia.). This slower feed was required to avoid chip-clogging of the 6060 T1, aluminum alloy while using an available drill head having chip braker geometry for steel. Additional data for drilling aluminum are presented in Table 8.

* The term "hognose" describes special carbide-tipped, round-point drill and insert type boring head for the drilling and boring of weapon components developed at Rock Island Arsenal.

TABLE 7

ECCENTRICITY READINGS FROM INSPECTION OF DRILLED PISTON

(RIA Part No. 1094135, 10895621)

Distance from Head (Inches)	Runout (Inch) at Indicated Radial Locations				Diameter (Inches)
	0°	90°	180°	270°	
44	0.000	-0.001	-0.0015	0.000	1.9740
30	0.000	- .001	-0.0005	-0.005	1.9715
20	0.0015	0.0025	-0.0005	0.000	1.9707
10	0.0005	0.0000	0.0000	0.005	1.9710
5	0.0000	0.0000	0.0025	0.003	1.9707
0.5	0.0008	0.0000	0.001	0.001	1.9713

TABLE 8
DATA FOR COOLANT-CHIP-EJECTOR DRILLING OF ALUMINUM*

<u>Alloy</u>	<u>Drill Diameter</u>	<u>Hole Depth</u>	<u>Speed</u>		<u>Feed</u>	
			<u>RPM</u>	<u>SFM</u>	<u>IPM</u>	<u>IPR</u>
6061 T-6	7/8 in.	36 in.	1150	265	4.8	.0042
	1-3/6 in.					
	1-3/5 in.	6 in.	1420	440	10.8	.0076
5460	1-1/4 in.	10 in.	955	310	7.8	.0082
2014 T-6	2 in.	15-3/4 in.	845	440	10.1	.0119
	1-15/16 in.	15-3/4 in.	655	330	6	.0092
7075 T-6	1-5/8 in.	12 in.	900	380	13.9	.0154
	0.952 in.	7-5/8 in.	1150	295	14.4	.0125
	1-1/4 in.	2 in.	1150	390	14.4	.0125

NOTE: Speed and feed are dependent upon the alloy and its heat treatment, and upon the drill diameter. Speed is determined more by the alloy; and feed is determined more by the drill diameter.

* Furnished by Mr. Ralph St. Clair, Clairco Tool Co.
 (Sandvik Distributor, Davenport, Iowa)

4. XM198 Gun Mount Regulator, RIA Part No. 73F 1201. The largest, standard drill head blank available, sharpened to 2.470-in. dia., was used at 287 RPM (186 SFM) and .0126 IPR (3.61 IPM) to convert multiple-step "hognose" core drilling of this part from 4140 steel tubing to single-step, coolant-chip-ejector drilling from 4140 steel solid stock.

A feed rate proportionally higher than the .0115 in. for drilling the same material with a 1.970-in. dia. drill was not possible because of the heavy chip flow through the ejector tube, and as indicated by Sandvik, .013 IPR feed appeared to be the maximum feed possible for this, largest diameter, drill.

5. 30mm Gun Barrel, RIA Part No. 69H40163. A 30mm gun barrel blank of Cr-Mo-V alloy was drilled with a 1.180-in. dia. drill at 750 RPM (232 SFM) and .005 IPR (5 IPM) using a steady rest at the center of the blank. This test, conducted with concern for resulting straightness due to the length-to-diameter ratio, showed the product to be well within tolerance. In similar tests conducted by Sandvik in a 58-in. long, 20mm barrels, the total indicated run out varied from 0.003 in. to 0.007 in. with a 60 RMS surface finish.

C. Drill Reconditioning and Resharpening

In conjunction with the in-house testing and adaptation to production drilling of weapons components, reconditioning and resharpening of the drill heads was evaluated. Modifications in chip-breaker geometry and a change in carbide grade to (C2:883") were also evaluated; however, no improvement in drill performance was observed. Furthermore, because of the costly fixturing and grinding which would be required to accurately duplicate the complicated insert geometry, salvaging of worn drills was not practical.

SUMMARY

The ejector drilling penetration rate in 4140 alloy proved to be approximately 1.6 times faster than the "hognose drilling" rate. Only a single pass through solid stock was required to form cylinders with the ejector drill compared to 2 passes (roughing and finishing) through precision tubing with the "hognose drill". Gun drilling of blanks prior to the 2-step "hognose" operation was also eliminated during the fabrication of pistons. Ejector drilling of the CG 27 alloy was approximately 30 times faster than conventional methods. Further benefits were gained by form grinding the outside cutting-insert of the ejector drill head to leave an internal chamfer or radius after drilling, thus eliminating subsequent machining operations.

Ejector drilling of the "potato masher" and recoil cylinders eliminated all stress-relieving heat treatments and straightening operations which were required between drilling operations when conventional manufacturing procedures are used. This advantage not only reduced time and manufacturing costs but eliminated scrap rates.

The findings concerning the greatly improved, workpiece surface integrities of finish, induced stresses, and work-hardening, and the finding of the vastly improved penetration rate for the difficult-to-machine, CG 27 alloy were significant. The uses of closer-allowance guide bushings and a smaller gap between the guide bushing and workpiece (beyond the drill manufacturers original recommendation) to achieve greater tool rigidity and life were also significant.

The long-sought drill, capable of rotating at carbide drill speeds, while penetrating metals at high speed steel drill feeds has been evaluated and successfully applied as a new, throwaway-type tool in the manufacture of weapons components.

RECOMMENDATIONS

It is recommended that the coolant-chip-ejector drill be applied whenever possible in the drilling of 0.787-in. dia. to 2.500-in. dia. holes over four diameters in depth, beyond which chip ejection is a problem in drilling with ordinary twist drills. Application is particularly recommended for drilling of 30mm and 40mm gun barrels.

It is recommended also that coolant-chip-ejector drilling be used to replace fabrication of cylindrical weapons components from tubing whenever possible; and that application of the drilling size-range be expanded by use of available, special, large-size drills, when high horsepower and coolant-capacity are available for the required workpiece and drill size. Also, this drill should be evaluated whenever possible in the machining of new, difficult-to-machine alloys and the scope of its applications be directed to include boring and trepanning.

Finally, it is recommended that continuing improvements in such drilling systems be monitored and tested. This would include the new drill heads with clamp-on, throw-away inserts and the Swiss-invented ejector drill^b which by-passes some incoming coolant to make the drill shank a hydrostatic bearing. In addition, the use of refrigerant-type or electro-chemical-type cutting fluids should be investigated.

^b U.S. Patent 3,511,120, "Official Gazette of the United States Patent Office," 12 May 1970, Alfred Kaser.

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- 4 U.S. Patent 3,511,120, "Official Gazette of the United States Patent Office," 12 May 1970, Alfred Kaser.

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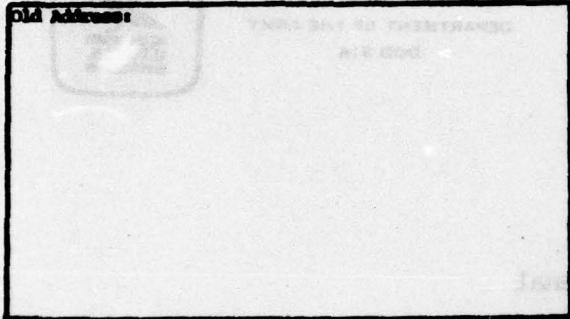
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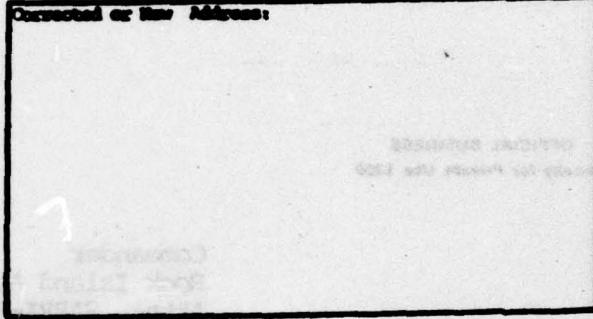
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The new drilling system was adaptable to existing in-house boring equipment and substantial cost savings have been realized, especially in the machining of Howitzer recoil mechanism components. Recommendations are made to expand the use of the Sandvik tool to include boring and trepanning.

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